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Forcing and Dissipation in Hot Jupiter Circulation Models

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Abstract

We use a general circulation model (GCM) to study the three-dimensional atmospheric flow and temperature structures of extrasolar planets on tidally synchronised orbits. We have performed an extensive exploration of the physical and numerical parameter space relevant for tidally synchronised giant planets, in idealised scenarios, using HD209458b as a reference planet. Here we focus on effects of applied thermal forcing, and the interplay between the forcing and numerical parameters, such as the strength of artificial viscosity. This is particularly crucial when the models are stressed in the limit of strong forcing, as is common in extrasolar planet studies. We show that commonly used forcing (a large range of cooling times, including very short ones) leads to unphysical (overdissipated and/or noisy) results. We emphasise that a variety of flow and temperature states is possible, not only for different values of the forcing parameters, but also for a given set of parameters. However, robust features can be identified, including large-scale coherent vortices which strongly affect the temperature distribution.

1. Background and Method

Most of the hot Jupiters (extrasolar giant planets on close-in orbits) that have been detected are likely to be spin-orbit synchronised. The resulting forcing condition for their atmospheres, where one hemisphere is perpetually and intensely irradiated, is different from any of the Solar System planets. Several groups have applied GCMs to understand the role of dynamics under this condition (e.g., [1]; [2]), outside the well-tested regimes where these models have traditionally been used.

We use the pseudospectral Community Atmosphere Model (CAM) to solve the full primitive equations for the atmospheric region from about 1 mbar to 100 bar. The thermal forcing is represented by simple Newtonian relaxation, specified by an equilibrium temperature profile, T_e, and a relaxation time scale, $\tau_{\rm th}$. Artificial viscosity is applied, which is necessary to damp poorly resolved oscillations and stabilise the integrations. The radius, mass, and orbital period (hence rotation rate) are derived from observations, using HD209458b as a reference planet. However, the appropriate values to use for T_e and $\tau_{\rm th}$, as well as initial conditions, are poorly constrained and must be varied systematically.

2. Robust States and Sensitivity

For different sets of T_e and $\tau_{\rm th}$, long-lasting stationary or oscillatory states are identified. Robust features include a small number of jets and large-scale coherent vortices (often in the form of a pair of modons). The large vortices commonly exhibit variability in time, translating or oscillating with corresponding variability in the position of relative hot and cold regions.

In addition, although robust features can be identified in general, we have found a significant sensitivity to the initial flow state, which is presently unknown for the extrasolar planets [3]. Thus, a variety of long-lasting states of the flow and temperature are possible, for a given set of physical and numerical parameters. The latter result highlights the unsuitability of using GCMs for making *quantitative* "predictions", such as for exact locations of temperature extremes on a given planet.

3. Relaxation and Dissipation Interaction

In the limit of strong forcing (short $\tau_{\rm th}$ and large gradients in T_e), which is commonly applied in extrasolar planet studies, the numerical models are stretched to or beyond their limits. Particularly important is the interplay between relaxation and artificial dissipation [4]. We demonstrate that a short relaxation time (much less than the planetary rotation time) leads to a large amount of unphysical, grid-scale oscillations in the simulation, which forces the use of excessive amounts of artificial viscosity to quench the oscillations. Hence, using a fixed strength of artificial viscosity in a simulation with a large range of $\tau_{\rm th}$ in the model domain (e.g., from about an hour to tens of days)—as done in many simulations in the literature—inevitably produces flow and temperature fields, which are either dominated by unphysical noise or overdamping.

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References

[1] Showman, A.P., Cooper, C.S., Fortney, J.J., & Marley, M.S., 'Atmospheric circulation of hot Jupiters: Three-dimensional circulation models of HD209458b and HD189733b with simplified forcing', *ApJ*, 682, 559-576, 2008

[2] Rauscher, E., Menou, K., 'Three-dimensional Modeling of Hot Jupiter Atmospheric Flows', *ApJ* 714, 1334, 2010

[3] Thrastarson, H. Th., Cho, J. Y-K., 'Effects of Initial Flow on Close-in Planet Atmospheric Circulation', *ApJ*, 716, 144, 2010

[4] Thrastarson, H. Th., Cho, J. Y-K., 'Relaxation Time and Dissipation Interaction in Hot Planet Atmospheric Flow Simulations', *ApJ*, 729, 117, 2011